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Investigation of Sensitivity of Fertilizer  
Grade Ammonium Nitrate to Explosion

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## SUMMARY

In order to determine the probable cause and mechanism of the explosion of cargoes of fertilizer grade ammonium nitrate on shipboard at Texas City, Texas, on 16 and 17 April 1947, an investigation has been made of the materials involved, possible contaminants, and the possibility of converting combustion of the bagged nitrate into a detonation.

It is indicated that both the nitrate and bags were of satisfactory quality and no deficiency in this respect was responsible for the fire which preceded the explosion.

The temperature required to cause the spontaneous ignition of bagged nitrate fertilizer has been found to be so high (150°C.) as to indicate the improbability of this being the origin of the fire on board the "Grand camp".

It has been found that the combustion of nitrate and paper or wood can produce gaseous products which can undergo explosion and in turn initiate the explosion of unconsumed nitrate fertilizer. A hypothesis of the mechanism of the Texas City disaster has been established on this basis.

**Investigation of Sensitivity of Fertilizer  
Grade Ammonium Nitrate to Explosion**

**INTRODUCTION:**

1. The explosion, on board the "Grandcamp" and "High flyer" at Texas City, Texas, on 16 and 17 April, respectively, of large quantities of fertilizer grade ammonium nitrate (FGAN) raised several questions having a bearing on possible causes of the explosions. Such an investigation was directed by Ref. A.

2. The FGAN, consisting of nitrate nodules coated with 0.75% wax and 3.5% clay, was packed in moisture-proofed, six-ply kraft paper bags holding 100 pounds of material. The packed FGAN, stowed on wooden dunnage, has been reported to have burned for over an hour before explosion on the "Grandcamp" and for a somewhat longer period on the "High flyer". Although ammonium nitrate has long been known to undergo detonation when initiated with a high explosive, no record is available here of a combustion involving this material being transformed into a detonation or of the material being detonated by heat alone.

3. The questions raised by the Texas City disaster for consideration at this Arsenal are summarized as follows:

a. Did the FGAN loaded on the ships deviate from specification requirements or contain objectionable impurities.

b. Could ignition of the cargo have been caused by reaction of the FGAN with the paper bagging or contaminants in the hold of the ship.

c. Can the combustion of a FGAN--paper or FGAN--wood mixture undergo transformation into detonation.

4. The existing literature throws little or no light on the last two of these subjects. This report summarizes the results of an investigation in the above directions and a thorough review of existing literature on the explosibility of ammonium nitrate.

**OBJECT:**

5. To test for compliance with specification requirements and the presence of unusual impurities samples of FGAN received from Ordnance facilities producing this material.

6. To determine the characteristics of bags used to pack FGAN and whether these are unduly reactive with FGAN.

7. To determine the reactivity and ignitability of mixtures of FGAN with possible contaminants under ship-loading conditions.

8. To determine if a mixture of FGAN and bagging paper can be caused to detonate by the application of heat alone, and the conditions required to bring about the transition from combustion to detonation.

**RESULTS:**

9. Analytical test data for 74 samples of FGAN received from Cornhusker,

Nebraska and Iowa Ordnance Plants and Milan Arsenal, recorded in Table I, show all these samples to comply with the requirements of the FDAP Specification of 8 July 1946 and Amendment 3 dated 14 February 1947 with the exception of a few insignificant deviations.

10. Special tests of 8 samples of FGAN from Nebraska Ordnance Plant (Table IIa) show these to be essentially free from harmful impurities and to be of the same order of sensitivity to impact, friction and heat as chemically pure ammonium nitrate.

11. Tests of samples of packing bags produced by three manufacturers and received from five Ordnance installations (Table II) show none of these contains acidic, mineral or reducing impurities in significant amount.

12. Charring and inflammation tests (Tables III and IV) of all bagging papers received for test show the differences between bags from the same manufacturer to be of the same orders as those between bags from different manufacturers. The presence of FGAN was found to result in charring of the bags at a temperature as low as 107°C. (225°F.), but temperatures from 177 to 232°C. (350° to 450°F.) were required to cause inflammation of the bag material in the presence of FGAN. The presence of 7 to 8% moisture in the bagging paper had no marked effect on the minimum temperatures required for charring and inflammation in the presence of FGAN.

13. 100°C. and 120°C. Vacuum Stability, 120°C. Mercury Displacement, Minimum Ignition Temperature and Exothermic Tests of mixtures of ammonium nitrate with bagging paper and possible contaminants, recorded in Tables V, VI and VII, may be summarized as follows:

a. Ammonium nitrate is appreciably reactive with dried sawdust, and dried or undried bagging paper, less reactive with iron, only slightly so with asphalt, and non-reactive with lubricating oil SAE 30 at 120°C. (248°F.).

b. The presence of 10% of sawdust or bagging paper in FGAN reduces the ignition temperature 70° to 200°C. for exposure times from 0.5 to 6 minutes and such mixtures can ignite at temperatures as low as 150°C. (302°F.) within 50 minutes.

c. Mixtures of FGAN with sawdust or bagging paper which react at 150°C. do so exothermically, but at temperatures of 135° and 120°C. the reactions are very slightly if at all exothermic.

14. Tests to determine the susceptibility of FGAN to detonation by impact or initiation, recorded in Tables VIII to X, show it to become as sensitive to impact as crystalline TNT when melted and tested at 17°C. to have rates of detonation of 1100 to 1350 m/sec. in the solid and 2100 m/sec. in the liquid state, and to have a fragmenting effect in the solid state approximately 24 percent of that of TNT at the same density.

15. Efforts to cause the detonation of FGAN alone by heating in a vented bomb (Table XI) caused no fragmentation of the bomb, but the evolution of fumes and heat indicated rapid reaction of the nitrate and coating wax and/or

partial exothermic decomposition of the nitrate at 150° to 165°C.

16. Numerous attempts to cause detonation by heating mixtures of FGAN with 1.5 to 10 percent of bagging paper in steel boxes and bombs (Tables XII and XIII) gave negative results, but in each case sufficient pressure was developed to rupture the container without fragmentation.

17. Efforts to cause the explosion of molten FGAN—bagging paper mixtures by dropping in cold or burning wood or charcoal gave negative results, and the presence of lubricating oil caused no explosion on heating (Table XIV). The impact on molten FGAN, contained in a steel pipe, of a 10-lb. weight falling 10 feet and on mixtures of molten FGAN with 5% bagging paper of a 52-lb. weight falling 10 feet was found to cause no explosion.

18. When a 1.6 gm. sample of FGAN was heated at 175°C. in a partially closed glass tube and, after 5 minutes, an electric spark was passed through the gases over the FGAN, a flash resulted.

19. By heating 10-gm. samples of FGAN at temperatures from 145° to 200°C. there were formed small quantities of carbon monoxide and quantities of nitrous oxide which increased with increase in temperature (Table XV).

20. Heating 10-gm. samples of a FGAN—bagging paper mixture at 175°C. yielded gases which contained much more (2.1 to 3.4%) carbon monoxide and from 2.0 to 4.5% of nitrous oxide. In three of the four tests ignition of the mixture occurred and in at least one case there was a marked two-phase explosion (Table XVI).

21. Heating of 5-lb. charges of FGAN and bagging paper in 6" x 11" bombs from which air had been removed caused no detonation, but heating of 10-lb. charges in the same type of bomb in which the air had been replaced with a mixture of carbon monoxide and nitrous oxide resulted in at least partial detonation or explosion of the charge as indicated by some cratering effect (Table XVII and photograph M-33030/1).

22. When 5.75-lb. charges of FGAN and bagging paper were heated in 2.5" x 36" bombs, with and without the replacement of air in the bomb by the CO-N<sub>2</sub>O mixture, incomplete, partial and practically complete fragmentation of the bombs resulted (Table XVIII and photographs M-33502, M-33503, M-33503/1 and M-33503/2).

23. There has been prepared an abstract of existing literature on the explosibility of ammonium nitrate which is inclosed as an appendix.

#### DISCUSSION OF RESULTS:

24. From the results of analytical tests of 74 samples recorded in Table I it is apparent that the FGAN being produced at the various Ordnance installations is of acceptable uniformity with respect to composition and granulation. As it was reported that all the FGAN on board the "Grand camp" had been manufactured at Nebraska Ordnance Plant, special tests were made of samples of eight lots manufactured at that Ordnance Plant shortly before and after the Texas City disaster. These were found (Table Ia) to be normal with respect to com-

position, granulation, sensitivity and ignitability and it is considered that the quality of the FGAN involved was not a factor in the fire and explosion on board the "Grand camp".

25. Similarly, it appears from the data in Table II that the packing bags delivered by three different manufacturers to the various Ordnance installations are of acceptable grade and free from objectionable impurities in significant amount.

26. Because of the occurrence of some boxcar fires of packed FGAN and the finding of some loaded bags which had become so discolored and embrittled as to be considered "charred", question has been raised as to the possibility that the packing of hot FGAN might cause deterioration of the paper and subsequent spontaneous ignition. Bursting strength tests showed normal bagging paper to have a value of 54 lb./sq.in., while the value was only 29 lb./sq.in. after heating at 100°C. for 18 days. Inflammability tests gave the following values:

	Minimum Values Required to Cause Inflammation	
	<u>Of,</u>	<u>Time, min.</u>
Normal bagging paper	800	0.75
Paper after charring	750	0.9
Paper after charring in contact with FGAN	450	300

From these data it is apparent that spontaneous ignition of FGAN and charred bagging paper could not take place at the temperatures prevailing in boxcars or the holds of ships.

27. This conclusion is confirmed by the results of the charring and inflammation tests recorded in Tables III and IV, which show that while contact with FGAN reduces the temperatures required to cause charring or inflammation of the bagging paper, the minimum temperature required to cause inflammation (177°C. or 350°F.) is far above any encountered in loading operations. It is somewhat surprising that the presence of 7 to 8% of moisture in the bagging paper has no marked effect on the temperature required for charring, but this may be due to the rapid loss of this moisture in the presence of hot FGAN. The fact that the differences between bags from different manufacturers are not greater than those between bags from a given manufacturer more or less disposes of the possibility that spontaneous ignition might have occurred because of the presence of defective bags.

28. It was thought that the presence in the hold of the ship of contaminants such as wood, oil, iron, paper and asphalt might have, in conjunction with spilled FGAN, led to spontaneous ignition and the fire which preceded the explosion on the "Grand camp". While the data in Tables V, VI and VII show FGAN is moderately reactive with iron and appreciably so with sawdust and paper, it appears that a temperature of approximately 150°C. (302°F.) is required to permit the reaction to lead to spontaneous ignition. While the data do not preclude spontaneous ignition because of the presence of some unsuspected contaminant, those ordinarily present do not appear to be responsible.

29. It has been shown that increase in initial temperature of the nitrate is reflected by increase in sensitivity to detonation (Ref. B) and rate of



detonation (Ref. C). This led to the thought that there might be a corresponding increase in sensitivity to impact, with the possibility that the combustion of bagging paper by molten FGAN might be converted into a detonation by the impact of a falling metallic body such as a structural member.

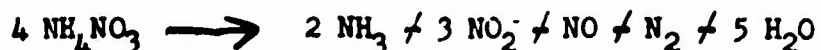
30. As shown by Table VIII, molten ammonium nitrate and FGAN are much more sensitive than the cold or hot solids, being of the same order of sensitivity to impact as solid TNT. Molten FGAN was found also to have a much higher rate of detonation (2109 m/sec., Table IX) than the solid, confined material (1350 m/sec.). However, the failure to obtain detonation of a confined molten FGAN--bagging paper mixture by subjecting it to the impact of a 52-lb. weight falling 10 feet indicates the improbability of detonation of molten, unconfined FGAN by impact during combustion.

31. Although it has been shown (Ref. D) that ammonium nitrate is not caused to explode by the sudden application of high temperatures, tests were made to determine if the impact of combustible material such as wood or charcoal on molten FGAN--bagging paper mixture or the sudden immersion of hot wood or charcoal would cause detonation (Table XIV). From the negative results of these tests it is considered unlikely that the explosion on the "Grand camp" was caused by falling or burning timber.

32. While heating of FGAN in a vented bomb with thermocouples embedded in the nitrate (Table XI) indicated exothermic decomposition of the FGAN or reaction between 150° and 165°C. of the nitrate and coating wax, numerous attempts to cause the detonation of FGAN--bagging paper mixtures by heating under strong confinement (Tables XII and XIII) resulted only in rupturing the bombs through the relatively slow development of high pressures. In no case was there evidence of fragmentation or cratering effects which would indicate at least partial detonation of the charge.

33. In view of the fact that the presence of 1% of petrolatum or as little as 0.2% of oil has been shown to sensitize ammonium nitrate under confinement to detonation by initiation (Ref. E) and by heat (Ref. F), the foregoing negative results were not taken as conclusive and a different approach was attempted.

34. Kaiser (Ref. G) has shown that ammonium nitrate heated to 200--260°C. can decompose according to the equation



and that this reaction is endothermic. At 269°C. there is an exothermic gas-phase explosion of the decomposition products, but this caused no explosion of residual, molten ammonium nitrate. It was found that when FGAN was heated to only 175°C. and a spark was passed through the gases above the nitrate, a flash resulted. Evidently the coating wax present was responsible for production of an explosive gas at a much lower temperature than that reported by Kaiser.

35. This led to the thought that there might be formed a significant quantity of carbon monoxide during decomposition of the nitrate and reaction with the coating wax. When samples of FGAN were heated at 145--200°C. (Table XV), it was found that significant amounts of carbon monoxide were formed, as well as nitrous oxide in proportions which increased with the temperature. When mixtures of FGAN and bagging paper were heated in a similar manner, in-

creased amounts of carbon monoxide were produced, ignition of the FGAN--paper mixture occurred in three cases, and there was a marked vapor-phase explosion in at least one case (Table XVI).

36. Bertholet and Vieille (Ref. H) have shown that a mixture of equal volumes of carbon monoxide and nitrous oxide can be detonated by a spark and has a rate of 1106 m/sec. Dilution with an inert gas such as nitrogen or relatively inert air might prevent such a detonation or decrease its rate. With this thought 95-5 mixtures of FGAN and bagging paper were heated in 6" x 11" bombs from which the air had been evacuated, but no detonations resulted (Table XVII). However, when the air was replaced with mixtures of carbon monoxide and nitrous oxide at different pressures, evidence of at least partial detonation of the charge was obtained (Photograph M-33030/1).

37. It was thought that the bombs used in these tests might have too great a relative diameter and that as the FGAN melted the bagging paper might rise to the surface and cushion the impact of any detonating wave from a gas mixture. Accordingly, longer and narrower bombs (2.5" x 36") were designed (Photograph M-33503/3) and the proportion of paper was decreased in subsequent tests recorded in Table XVIII. Under these conditions, definite detonations of much of the FGAN charges were obtained when the air in the bomb was replaced with the gas mixture (Photographs M-33502, M-33503 and M-33503/1). When the bagging paper was in the form of twelve narrow strips distributed lengthwise in the FGAN charge and the air in the bomb was removed but not replaced, almost complete detonation of the charge was obtained on heating as shown by the high degree of fragmentation of the bomb. A heating test with a similar bomb loaded with Ottawa sand showed the same amount of heat to produce a temperature of 310°C. at the inner face of the bomb wall and of 230°C. at the center of the sand charge.

38. We may therefore visualize the detonation of bagged FGAN in the Texas City disaster as follows: Accidental ignition of the bagging or wooden dunnage was followed by slow combustion with ammonium nitrate, rather than air, supplying the necessary oxygen. The heat evolved by this combustion served to melt additional FGAN, and the nitrate reacted with coating wax, paper bagging and wood to produce carbon monoxide and nitrous oxide as well as heavy acid gases. This mixture, being heavier than air, displaced the air in the hold of the ship. After the hatch had been battened down, the gas pressure in the hold increased, as shown by the testimony of witnesses. When the carbon monoxide--nitrous oxide mixture reached its lower limit of concentration for ignition or was heated to its ignition point, this underwent detonation. The detonation of the gas mixture evidently was sufficient to initiate the detonation of molten FGAN and probably part of the hot but still solid FGAN.

39. While this can never be proved to have occurred, it seems the most reasonable hypothesis of the mechanism of the explosion that is supported by existing data. On the basis of this hypothesis it is believed that in case of accidental ignition of bagged FGAN in warehouses or ships it is important to avoid confinement of the gases produced.

#### CONCLUSIONS:

A. The quality of the nitrate fertilizer and the paper bags tested in the course of this investigation is entirely satisfactory and is not indicated to be a contributory factor in the explosion at Texas City, Texas.



B. Since tests indicate a minimum temperature of approximately 150°C. (302°F.) to be required for the spontaneous ignition of bagged nitrate fertilizer, it is concluded that spontaneous ignition is a highly improbable cause of the fire on board the "Grand camp" unless there existed special conditions beyond conjecture.

C. The combustion and heating of a mixture of FGAN with bagging paper or wood can result in the formation of a gas mixture containing carbon monoxide and nitrous oxide which can undergo explosion.

D. The combustion of a FGAN-paper mixture can be transformed into detonation under conditions of confinement.

E. It is probable that the explosions of FGAN cargoes on shipboard at Texas City, Texas are attributable to a primary explosion of gases produced during the fires which preceded explosions of the cargoes.

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Table I

Specification Tests of Ammonium Nitrate (Fertilizer Grade).

Sample Designation	Received from		Moisture, %	Ether Soluble, %	Water Insoluble, %	Total Nitrogen, %	Granulation		
							Thru No. 8 <sup>a</sup>	On No. 35 <sup>a</sup>	Thru No. 100 <sup>a</sup>
134	Iowa	OP	0.07	0.85	3.30	32.98	100	51.3*	4.6
135	"	"	0.05	0.84	3.44	32.96	100	60.3	4.3
139	Nebraska	OP	0.05	0.90	3.26	33.39	100	74.1	2.0
143	Iowa	OP	0.08	0.71	2.70	33.01	100	65.0	5.3
144	"	"	0.06	0.93	3.07	33.14	100	62.6	2.8
145	"	"	0.08	0.90	3.14	33.25	100	61.6	4.4
146	"	"	0.09	0.84	3.38	32.98	100	66.4	3.6
148	"	"	0.04	0.84	3.01	33.16	100	61.0	2.4
152	"	"	0.07	0.88	3.06	33.16	100	67.2	2.4
154	"	"	0.05	0.90	3.09	33.18	100	61.2	3.8
156	"	"	0.05	0.84	3.27	33.14	100	66.4	2.4
157	"	"	0.05	0.96	3.09	33.00	100	57.0	4.2
158	"	"	0.03	0.88	2.98	33.22	100	64.0	3.6
160	"	"	0.04	0.80	3.00	33.16	100	63.4	2.8
161	"	"	0.06	0.83	3.23	33.21	100	64.0	3.4
163	"	"	0.04	0.98	2.89	33.07	100	59.0	7.4
167	"	"	0.05	0.81	2.96	33.12	100	65.0	4.0
168	"	"	0.06	0.90	3.20	33.01	100	57.6	5.4
169	"	"	0.07	0.91	3.36	33.01	100	65.4	3.8
170	"	"	0.08	0.85	3.26	33.10	100	66.4	5.6
171	"	"	0.05	0.80	2.88	33.21	100	64.0	3.4
172	"	"	0.04	0.95	3.27	33.01	100	64.6	4.2
173	"	"	0.05	0.82	3.09	33.01	100	64.2	4.3
174	"	"	0.04	0.90	2.99	33.07	100	64.8	5.0
176	"	"	0.04	0.85	2.53	33.31	100	61.0	6.7
178	"	"	0.04	0.95	2.93	33.23	100	66.4	3.4
179	"	"	0.04	0.97	3.34	32.91	100	61.8	4.2
572	Nebraska	OP	0.04	0.73	3.01	33.57	100	66.0	4.0
573	"	"	0.04	0.80	2.64	33.72	100	84.2	1.6
574	"	"	0.04	0.91	3.11	33.62	100	77.2	1.2
577	"	"	0.05	0.72	2.77	33.78	100	75.0	2.0
578	"	"	0.04	0.73	2.74	33.66	100	70.0	2.8
579	"	"	0.05	0.73	2.75	33.71	100	72.8	2.2
580	"	"	0.03	0.73	2.70	33.66	100	63.4	3.2
581	"	"	0.05	0.78	3.06	33.55	100	65.6	3.4
582	"	"	0.04	0.78	2.77	33.60	100	61.2	3.6
583	"	"	0.04	0.87	2.90	33.47	100	67.8	2.8
585	"	"	0.04	0.79	2.93	33.59	100	76.4	1.2
587	"	"	0.03	0.77	2.98	33.49	100	64.6	4.2
Prescribed <sup>b</sup>			0.25	0.75 ±	3.50 ±	32.50	100	55	8
			Max.	0.35	1.00	Min.	Min.	Min.	Max.

<sup>a</sup> U.S. Standard sieve.

<sup>b</sup> By FDAP specification for Ammonium Nitrate (Fertilizer Grade) with Amendment 3.

\* Fails to comply with specified limit.

Table I (Continued)

Sample Designation	Received from		Moisture, %	Ether Soluble, %	Water Insoluble, %	Total Nitrogen, %	Granulation		
							Thru No. 8 <sup>a</sup>	On No. 35 <sup>a</sup>	Thru No. 100 <sup>a</sup>
588	Nebraska	OP	0.04	0.79	2.92	33.58	100	74.4	2.8
539	"	"	0.03	0.73	3.20	33.54	100	75.8	1.8
590	"	"	0.03	0.77	2.99	33.58	100	63.4	4.6
591	"	"	0.05	0.79	3.08	33.26	100	59.6	4.2
592	"	"	0.04	0.88	3.00	33.47	100	62.2	3.2
593	"	"	0.04	0.75	3.09	33.47	100	63.2	4.0
594	"	"	0.04	0.88	2.97	33.53	100	60.8	4.0
595	"	"	0.04	0.77	2.78	33.59	100	80.4	1.2
597	"	"	0.04	0.76	2.84	33.64	100	77.6	1.4
598	"	"	0.04	0.76	3.01	33.62	100	78.0	2.0
600	"	"	0.04	0.75	2.82	33.63	100	74.8	2.4
601	"	"	0.04	0.71	2.92	33.66	100	83.4	0.8
602	"	"	0.05	0.72	2.99	33.63	100	79.6	2.8
1124	Silas Mason Co.		0.04	0.59	3.78	33.14	100	83.9	0.3
2097	Iowa	OP	0.04	0.55	2.58	33.78	100	74.6	7.2
3388	Milan Arsenal		0.03	0.58	2.77	33.70	100	72.6	1.0
3809	Silas Mason Co.		0.03	0.42	2.60	33.74	100	62.3	10.8*
3809	Silas Mason Co.		0.03	0.60	3.58	33.28	100	75.1	2.4
8694	Cornhusker	OP	0.05	0.66	2.16	33.90	100	84.0	0.7
COP, F718	"	"	0.06	0.57	2.42*	33.52	100	73.9	1.8
COP, F719	"	"	0.08	0.85	2.67	33.75	100	68.4	4.5
COP, F720	"	"	0.05	0.77	3.09	33.71	100	70.0	4.5
COP, F721	"	"	0.06	0.99	3.19	33.27	100	67.4	4.3
COP, F722	"	"	0.06	0.65	2.55	33.83	100	67.9	4.9
COP, F723	"	"	0.06	0.94	2.67	33.57	100	62.7	6.3
COP, F724	"	"	0.06	0.74	2.93	33.64	100	76.7	2.4
COP, F725	"	"	0.06	0.64	2.85	33.75	100	76.5	7.0
COP, F726	"	"	0.06	0.70	2.94	33.42	100	65.3	5.2
COP, F727	"	"	0.06	0.66	3.31	33.61	100	69.7	2.4
COP, F728	"	"	0.08	0.66	2.78	33.55	100	74.4	2.3
COP, F729	"	"	0.04	0.63	2.67	33.61	100	79.0	2.1
COP, F730	"	"	0.05	0.63	2.96	33.62	100	72.2	3.2
COP, F731	"	"	0.07	0.65	2.53	33.73	100	69.6	4.8
COP, F732	"	"	0.06	0.74	2.58	33.64	100	71.0	1.9
COP, F733	"	"	0.07	0.77	3.24	33.45	100	70.7	3.6
Prescribed <sup>b</sup>			0.25 Max.	0.75 ± 0.35	3.50 ± 1.00	32.50 Min.	100 Min.	55 Min.	8 Max.

<sup>a</sup> U.S. Standard sieve.

<sup>b</sup> By PDAP specification for Ammonium Nitrate (Fertilizer Grade) with Amendment 3.

\* Fails to comply with specified limit.

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Table Ia

Special Tests of Samples of FGAN Received from Nebraska OP.

Lot Car Number	575 SP	576 P&E	584 SOU	586 ATSP	596 CM	599 SAL	Special Coated with FRP
	32829	3724	161852	123492	7994	11323	
Shipped	25/3/47	25/3/47	26/3/47	27/3/47	28/3/47	28/3/47	
Acidity, %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrites, %	None	None	None	None	None	None	None
Phenols, %	"	"	"	"	"	"	"
Ferrocyanides, %	"	"	"	"	"	"	"
Pyridine, %	"	"	"	"	"	"	"
Thiocyanates, %							
Less than	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Impact Test, PA App., 2 Kg. Wt., inches	30	32	31	30	31	31	29
Pendulum Friction Test, Steel Shoe							
No. Trials							
Unaffected							
Rifle Bullet Impact Test							
No. Trials							
Unaffected							
Explosion Temp. Test, °C.	333	344	338	338	335	338	382

- a - Value for CP ammonium nitrate, 31 inches.  
b - Temperature required to cause explosion in 3 sec.  
Value for CP ammonium nitrate, 325°C.

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Table II

Chemical Tests of Ammonium Nitrate Fertilizer Bags.

Supplier: Received from:	Bagpak Inc.				Union Paper and Bag Corp.				St. Regis Sales Corp.			
	Iowa FDAP	Nebraska Ord. Plant	Cornhusker Ord. Plant	Iowa Ord. Plant	Nebraska Ord. Plant	Cornhusker Ord. Plant	Illinois Ord. Plant	Iowa Ord. Plant	Nebraska Ord. Plant	Illinois Ord. Plant	Iowa Ord. Plant	Nebraska Ord. Plant
Acidity (as H <sub>2</sub> SO <sub>4</sub> ), %	0.01	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.013	0.008
pH of water extract <sup>a</sup>	7.0	7.1	7.1	7.1	7.1	7.1	7.2	7.1	7.1	7.2	7.1	6.9
Sulphite (as Na <sub>2</sub> SO <sub>3</sub> ), %, less than	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Reducing value, mls. of 0.1N												
KMnO <sub>4</sub> per gram of sample	1.4	1.6	1.2	1.4	1.2	1.6	2.0	1.2	1.6	1.4	1.3	1.0
Ash, %	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.0
Total sulphate (as CaSO <sub>4</sub> ), %	41	46					60				46	
Composition of ash:												
Calcium (as sulphate), %	34	34	0	0	0	0	47	0	0	0	31	0
Magnesium (as sulphate), %	12	15	0	0	0	0	18	0	0	0	16	0
Sodium (as sulphate), %	6	10	0	0	0	0	12	0	0	0	12	0
Silica, %	30	20	0	0	0	0	8	0	0	0	21	0
Iron and aluminum (as oxides), %	20	20	0	0	0	0	19	0	0	0	18	0
Copper (as oxides) %, less than	1	1	0	0	0	0	1	0	0	0	1	0
Chromium (as oxide), % less than	1	1	0	0	0	0	1	0	0	0	1	0
Manganese (as oxide), % less than	1	1	0	0	0	0	1	0	0	0	1	0

<sup>a</sup> - The unimpregnated layers of paper only were used for these tests.

<sup>b</sup> - The total sulphate contents were such as to indicate that these metals were present essentially as the sulphate.

<sup>c</sup> - Comparison of the spectrograms of these ashes and those of the other four samples indicated (1) the composition of all the ashes to be qualitatively similar and (2) the percentage composition of these ashes to come within the range of the above reported values.

Table III

Minimum Temperature-Time Charring<sup>a</sup> Values of Envelopes Made from Submitted Fertilizer Bags.

Bag Manufacturer	Source of Bag	I		II		III		IV	
		Paper Envelope		Paper Envelope Ammonium Nitrate (F.G.) Inside		Paper Envelope Ammonium Nitrate (F.G.) Inside and Dusted on Outside		As Mo. III, but Envelope Previously Conditioned to Contain Approx. 7-8% Added Moisture	
		Temp. of.	Time hrs.	Temp. of.	Time hrs.	Temp. of.	Time hrs.	Temp. of.	Time hrs.
Bagpak, Inc.	FDAP	400	20-24	225	48-56 44-48	225	48-56 64-72	-	-
	1A	400	20-24	225	48-56 64-72	225	48-56 64-72	225	48-56 48-56
	NEB	400	20-24	225	48-56	225	48-56	225	48-56
	CH	400	20-24	225	48-56 48-56	225	48-56 48-56	225	48-56
St. Regis	1A	400	20-24	225	48-56 64-72	225	48-56 64-72	225	48-56 48-56
	NEB	400	20-24	225	48-56 48-56	225	48-56 48-56	225	48-56
	1A	400	20-24	225	48-56 64-72	225	48-56 64-72	225	48-56 48-56
Union	1A	400	20-24	225	48-56 64-72	225	48-56 64-72	225	48-56 48-56
	NEB	400	20-24	225	48-56 48-56	225	48-56 48-56	225	48-56 48-56
	CH	400	20-24	225	48-56 48-56	225	48-56 48-56	225	48-56 48-56
	ILL	400	20-24	225	48-56 48-56	225	48-56 48-56	225	48-56 48-56

<sup>a</sup> - Where more than 1 determination was made of the minimum time required for charring to occur at the minimum temperature, the results of the individual determinations are given.



Table IV

Minimum Temperature-Time Inflammation Values<sup>a</sup> of Envelopes Made from Submitted Fertilizer Bags.

Assembly:	Bag Manufacturer Bagpak, Inc.	Source of Bag FDAP	I Paper Envelope		II Paper Envelope Ammonium Nitrate (F.G.) Inside		III Paper Envelope Ammonium Nitrate (F.G.) Inside and Dusted on Outside		IV As No. III but Envelope Previously Conditioned to Contain Approx. 7-8% Added Moisture	
			Temp. Op. 850	Time min. 0.6	Temp. Op. 400	Time min. 12	Temp. Op. 375	Time min. 40	Temp. Op. -	Time min. -
St. Regis	LA	1A	750	1.0	400	12	400	13	-	-
				1.1		16		11		
	NEB	NEB	775	1.0	450	16	450	5	-	-
				1.3		11		5		
Union	CH	CH	800	1.1	400	12	375	31	-	-
				1.1		19				
	LA	1A	750	0.9	450	11	350	29	375	23
						15				
Union	NEB	NEB	750	1.5	400	16	400	19	-	-
				1.3				17		
	LA	1A	750	1.1	450	6	375	40	400	15
				1.1		7				
Union	NEB	NEB	775	1.2	450	10	400	18	-	-
						7		16		
	CH	CH	750	1.3	450	6	450	16	-	-
						12		17		
Union	ILL	ILL	800	1.0	375	15	350	65	450	7
				1.1		26		103		

KEY: IA - Iowa, NEB - Nebraska, CH - Cornhusker, ILL - Illinois

<sup>a</sup> - Where more than 1 determination was made of the minimum time required for ignition to occur at the minimum temperature, the results of the individual determinations are given.  
<sup>b</sup> - When bagging papers were heated for 2 hours at temperatures 50°F. below their minimum inflammation temperatures the material smoked, frequently glowed, charred and ashed but did not inflame. Bagging papers treated with FGAM did the same at temperatures 25°F. below their minimum inflammation temperatures.

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Table V  
Reactivity of Ammonium Nitrate with Possible Contaminants.

CP	Nit- rate, gm.	FCAN, gm.	Paper		Dry gm.	Paper Damp, gm.	Dry gm.	Saw- dust, gm.	Asph- alt, gm.	Oil <sup>a</sup> , gm.	Powd. Iron, gm.	100° C. VS		120° C. VS		120° C. Merc.	
			gm.	gm.		gm.	gm.					cc.	hr.	cc.	hr.	cc.	hr.
-	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	2.5	-	-	-	-	-	-	-	-	-	-	0.48	40	-	-
-	-	-	-	-	2.5	-	-	-	-	-	-	-	-	0.50	40	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.40	40	-	-
-	-	-	-	-	-	-	-	2.5	-	-	-	-	-	0.44	40	-	-
-	-	-	-	-	-	-	-	-	2.5	-	-	-	-	0.38	40	-	-
-	-	-	-	-	-	-	-	-	-	-	2.5	-	-	0.09	40	-	-
2.5	-	-	2.5	-	-	-	-	-	-	-	-	0.75	40	11.7	40	-	-
2.5	-	-	-	-	2.5	-	-	-	-	-	-	1.50	40	11.7	16	-	-
2.5	-	-	-	-	-	-	-	2.5	-	-	-	-	-	0.53	40	-	-
2.5	-	-	-	-	-	-	-	-	2.5	-	-	-	-	0.38	40	-	-
2.5	-	-	-	-	-	-	-	-	-	-	2.5	3.45	40	11.7	16	-	-
1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	106
-	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	106
-	-	1.5	1.5	-	-	-	-	-	-	-	-	-	-	-	-	8.2	106
-	-	-	-	1.5	-	-	-	-	-	-	-	-	-	-	-	42.2	106
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.3	106
-	-	-	-	-	-	-	-	1.5	-	-	-	-	-	-	-	6.4	106
-	-	-	-	-	-	-	-	-	1.5	-	-	-	-	-	-	0.0	106
-	-	-	-	-	-	-	-	-	-	-	1.5	-	-	-	-	0.0	106
-	1.5	1.5	1.5	-	-	-	-	-	-	-	-	-	-	-	-	68.7	70
-	1.5	1.5	-	1.5	-	-	-	-	-	-	-	-	-	-	-	68.7	24
-	1.5	1.5	-	-	1.5	-	-	-	-	-	-	-	-	-	-	42	106
-	1.5	1.5	-	-	-	-	-	1.5	-	-	-	-	-	-	-	32.8	106
-	1.5	1.5	-	-	-	-	-	-	1.5	-	-	-	-	-	-	0.5	106
-	1.5	1.5	-	-	-	-	-	-	-	-	1.5	-	-	-	-	17.8	106

<sup>a</sup> Lubricating, SAE 30.

Table VI

Minimum Time-Temperature Requirements for the Ignition of FGAN and Mixtures with Saw dust or Paper.

Time for Ignition, min.	Min. Temp., °C., for Ignition of 10 gm. of		
	100% FGAN	10% Sawdust 90% FGAN	10% Paper 90% FGAN
0.5	780	580	580
3	410	310	310
6	310	240	240
20-30	300 <sup>a</sup>	-	-
8	-	200	-
12	-	-	200
15	-	160	-
18	-	-	160
26	-	150	-
50	-	-	150

<sup>a</sup> Decomposition with ignition.

Table VII

Thermochemical Tests of FGAN and Mixtures of It with Paper and Sawdust.

Composition, %			
FGAN <sup>a</sup>	100	90	90
Bagging Paper	-	10	-
Dried sawdust	-	-	10
Bath Temp., °C.	120	120	120
Max. Temp., °C.	118.4	117.3	118.0
Bath Temp., °C.	134.5	134.5	134.5
Max. Temp., °C.	134.9	134.9	134.3
Bath Temp., °C.	150	150	150
Max. Temp., °C.	149.1	184.0	160.2
			172.0
Time, hours	5.5	3.5	0.6
			1.25

NOTE: 10-gram samples were placed in standard 134.5°C. Heat Test tubes with a thermometer bulb imbedded in the sample. The tube then was placed in a Heat Test bath maintained at 120° or 134.5°C. or in a liquid bath maintained at 150°C. The temperature of the sample was recorded periodically and the maximum value obtained is recorded above. In the tests at 150°C. the rises in temperature of the samples occurred 35 to 40 minutes after heating had started. The temperatures of the mixtures decreased to that of the bath within a few minutes after the maximum had been attained. Heating was continued for some time without further exothermic effect.

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Table VIII

Effect of Temperature on Impact Sensitivity of  
Ammonium Nitrate.

Temperature, °C.	Impact Test, PA App., 2 Kg. Wt., for	
	CP Nitrate	FGAN <sup>a</sup>
25	31	30
75	28	31, 31
100	27	22
150	27	23
175 <sup>b</sup>	12	12, 13

<sup>a</sup> Coated with Wax B.

<sup>b</sup> Nitrate in molten condition.

Table IX

Rate of Detonation of FGAN<sup>a</sup>.

Method	Combined <sup>b</sup> Solid	Unconfined Solid	Molten
	D'Autriche	D'Autriche	Drum camera
Length of column	51"	48"	44 cm.
Diameter of column	1.25"	4.5"	3 cm.
Density, gm./cc.	0.90 0.92	0.90	1.4
Booster	<sup>c</sup>	<sup>d</sup>	
Rate, m./sec.	1370 <sup>c</sup> 1330	1106 <sup>d</sup>	2109

<sup>a</sup> Coated with Wax B.

<sup>b</sup> In seamless steel tubing 0.25 inch wall thickness

<sup>c</sup> 50 grams of Composition A-3 with Engineer Corps Special Blasting Cap.

<sup>d</sup> 0.5 lb. of Composition C. Detonation died out with 0.25 lb. of Composition C.

<sup>e</sup> 50 grams of Composition A-3. Molten FGAN did not detonate when initiated by Engineer Corps Special Blasting Cap alone.

Table X

Brisance of FGAN by Fragmentation of 40 mm. Shell

	FGAN	TNT
Av. Weight of Charge, gm.	44.3	44.7
Av. Density of Charge, gm./cc.	1.0	1.01
Av. Total number of fragments	16	66

Table XI

3-Inch Vented Pipe Bomb<sup>a</sup> Tests of FGAN.

FGAN, lbs.	10	10	10
Position of bomb	Horizontal	Vertical	Vertical
Temperature, °C.			
FGAN heated to	165	150	160 <sup>2</sup> / <sub>5</sub>
Maximum recorded	575	160	160 <sup>2</sup> / <sub>5</sub>
Effect on bomb	None Red fumes evolved.	Screw plug blown out.	Upper cap blown loose.

<sup>a</sup> Equipped with thermocouples and heated electrically.

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Table XII

Heating Tests of FGAN and Bagging Paper in 1/4" Steel  
Simulated Smokeless Powder Shipping Containers (Welded).  
(Photographs M-33017 and M-33018)

Test No.	<u>1</u>	<u>2</u>
Date	28/4/1947	30/4/1947
Charge		
FGAN, lb.	100	50
Bagging Paper, lb.	1.5	4.5
Position of Container	Horizontal	Vertical
Method of Heating	Bonfire	Bonfire
Time of Heating, minutes	11	8
Result	Rupture at end.	Rupture at end.
Photograph	M-33260	M-33028



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Table XIII  
Heating Tests of FGAN and Bagging Paper in 5/16" Welded  
Steel Bombs.  
(6" dia., 11" depth, Photograph M-33030)

Date of Test Vent in top of bomb, in. dia.	16/5/47	16/5/47	19/5/47	19/5/47	22/5/47	23/5/47	23/5/47
					1/16	1/4	
Charge							
FGAN, lb.	10	10	10	10	10	10	10
Bag paper, lb.	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Igniting Agent							
Position of Bomb	Vertical	Vertical	<sup>a</sup> Hor.	Hor.	Vertical	Vertical	Vertical
Method of Heating	Bonfire	Bonfire	Bonfire	Bonfire	Bonfire	Bonfire	Bonfire
Rate of Heating	Rapid	Slow	Rapid	Slow	Rapid	Rapid	Rapid
Time of Heating, min.	6	8	5	12	6	6	6

Result  
In each case the bomb was ruptured at the top or bottom but without any evidence of detonation of the charge. Rupture in each case appeared to be caused by gradually developed pressure, without fragmenting or cratering effects.

<sup>a</sup> - Two No. 8 blasting caps with charge of black powder and lead styphnate.



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Table XV

Gases Produced by Heating FGAN<sup>a</sup>.

FGAN, g.	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>	<u>10</u>
Max. Temp., °C.	120	120	145	180	200
Initial Bath Temp., °C.	25	25	25	25	200
Time of Heating, min.	180	30	60	90	120
Initial Pressure, cm. Hg.	1	20	20	1	1
<u>Composition of Gas, %</u>					
Carbon monoxide	0.0	0.0	0.4	0.0	0.5
Nitrous oxide	0.0	0.0	0.0	1.2	18.1
Nitric oxide	0.0	0.0	0.0	0.0	0.0
Acid gases <sup>b</sup>	0.0	0.0	0.5	0.0	2.0
Hydrogen	0.0	0.0	0.0	0.0	0.0
Nitrogen	79.2	79.0	78.6	77.2	65.7
Oxygen	20.8	21.0	20.5	21.6	13.7

<sup>a</sup> Coated with Wax B.

<sup>b</sup> Nitrogen dioxide and/or carbon dioxide.

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Table XVI

Gases Produced by Heating  
Mixtures of  
FGAN<sup>a</sup> and Bagging Paper.

FGAN, gm.	9	9	9	9
Bagging paper, gm.	<u>1</u>	<u>1</u>	<u>1</u>	<u>1</u>
Max. Temp., °C.	175	175	175	175
Initial Bath Temp., °C.	25	175	175	175
Time of Heating, min.	45	50	50	50
Initial Pressure, cm. Hg.	20	1	1	1
<u>Composition of Gases<sup>c</sup>, %</u>				
Carbon monoxide	3.4	2.1	3.4	3.4
Nitrous oxide	4.5	2.2	2.0	<sup>e</sup>
Nitric oxide	4.0	0.0	0.0	<sup>d</sup>
Acid gases <sup>b</sup>	15.5	6.5	18.9	13.0
Hydrogen	0.0	0.0	0.0	0.0
Nitrogen	72.6	74.2	69.5	-
Oxygen	0.0	15.0	6.2	0.0
Ignition	Yes	Yes	No	Yes
Explosion of gases in flask	Marked	Slight	None	None

<sup>a</sup> Coated with Wax B.

<sup>b</sup> Nitrogen dioxide and/or carbon dioxide.

<sup>c</sup> Insufficient sample for test.

<sup>d</sup> Present in large proportion.

<sup>e</sup> The mixtures were heated in 250 ml. flasks connected to partially evacuated gas-collection bulbs by capillary tubing. The gases analyzed were those evolved prior to any explosion in the flask or at the end of the experiment.

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Table XVII

Heating Tests of FGAN and Bagging Paper in 5/6" Welded Steel Bombs.  
(6" dia., 11" depth, Photograph M-33030)

Date of Test	16/6/47	18/6/47	19/6/47	24/6/47
Charge				
FGAN, lb.	4.5	4.5	9.5	9.5
Bagging paper, lb.	0.5	0.25	0.5	0.5
Atmosphere in bomb	Evacuated	Evacuated	Evacuated	Evacuated
Carbon monoxide, atm.	-	-	1	3
Nitrous oxide, atm.	-	-	1	3
Position of Bomb	Horizontal	Vertical	Horizontal	Vertical
Method of heating	Electric oven.	Electric resistance wire.	Electric resistance wire.	Electric resistance wire.
Maximum Temp., °C.	175	-	-	-
OF.	347	-	-	-
Time of heating, min.	165	50	35	55
Result	Closing plug blown out. No evidence of detonation.	Closing plug blown out. No evidence of detonation.	Closing plug blown out. Cratering effect indicated. Photograph M-33030/1.	Bottom of bomb blown out. Steel plate under bomb bent slightly.

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Table XVIII

Heating Tests of FGAN and Bagging Paper in 2.5"  
1.d. x 36" Welded Steel 0.125" Pipe Bombs.  
(Photograph M-33503/3)

Date of Test	<u>27/6/47</u>	<u>2/7/47</u>	<u>3/7/47</u>
<u>Charge</u>			
FGAN, lb.	5.7	5.7	5.7
Bagging paper, lb.	0.006	0.006	0.06 <sup>a</sup>
<u>Atmosphere over charge</u>	Evacuated	Evacuated	Evacuated
Carbon monoxide, atm.	3	1	-
Nitrous oxide, atm.	3	1	-
Position of Bomb	Vertical	Vertical	Vertical
Method of heating	Electrical resistance wires.		
Time of heating min.	50	46	50
Result:	Bomb sheared, bent and folded. Incomplete detonation.	Bomb sheared, bent folded and broken. More complete detonation.	Bomb fragmented. Almost com- plete de- tonation of charge.
Photograph	M-33502 M-33503	M-33503/1	M-33503/2

<sup>a</sup> In long narrow strips (12) extending lengthwise through charge.



• Picatinny Arsenal  
11 June 1947

WRTomlinson, Jr./HAAaronson/abl

Review of Literature on the Explosive  
Properties of Ammonium Nitrate (AN)

1. "The Explosibility of Ammonium Nitrate" by Chas. E. Munroe -  
Chem. Met. Eng. 26, 529 (1922).

AN burns when thrown on red-hot porcelain, explodes when thrown on red-hot charcoal.

AN explodes when initiated, in 80 mm Shell, by 3 gm mercury fulminate, and more violently if 10 gm bellite is used.

L'heure claims complete explosion of 50 gm AN Charges in a clay borehole with initiation by cordeau, and stemming.

AN can sometimes be exploded by blasting gelatin.

Heating AN increases its sensitivity.

2. "The Influence of Confinement upon the Explosibility of Ammonium Nitrate" by J. L. Sherrick - Army Ord. 4, 329-333 (1924)

Attempts to detonate AN at 0.7 gm/cc in 1.5 in. I.D.,  $\frac{1}{4}$  in. thick Shelby Steel tubing, using 100 gm boosters of TNT, tetryl, picric acid, TNA or high AN explosive did not lead to more than feeble partial explosion.

3. "The Influence of Density of Packing Upon the Explosibility of Ammonium Nitrate" by J. L. Sherrick -  
Army Ord. 4, 395-400 (1924)

Results similar to those shown in Ref. 2, explosibility of AN decreases with (a) increasing density (b) decreasing confinement.

4. "The Influence of Temperature on the Explosibility of Ammonium Nitrate" by G. W. Jones - Army Ord. 5, 599-603 (1925)

AN is more explosible at higher temperatures, with a marked increase in explosibility occurring when the temperature is raised above some point in the range 120 - 140°C. Boosters of higher brisances are more effective in exploding AN than those of lower brisance.

5. "Famous Nitrate Fires of History" by C. E. Munroe -  
Chem. Met. Eng. 31, 926 - 966 (1924)

Potassium and sodium nitrate, in contact with combustible matter, in large masses can be ignited by sparks, lightning, blasting or may ignite spontaneously in the presence of reactive impurities such as acid. Addition of small amounts of water, or application of sufficient impact force, may cause explosion of the burning mass.

6. "The Influence of Temperature on the Explosibility of Ammonium Nitrate" by D. B. Gawthrop - Army Ord 6, 47-50 (1925)

The sensitivity to initiation of AN increases with temperature, the detonation rate rising uniformly from 1050 m/s at 15°C to 1500 m/s at 140°C, using AN at 0.70 gm/cc, in 3.59 cm I.D., 0.2 in. thick Shelby Steel tubing, when 75 gm boosters of lightly tamped picric acid are used.

7. "Destruction of Muscle Shoals Ammonium Nitrate by Fire And Explosion" - Ind. Eng. Chem. 17, 819 (1925)

Two carloads of AN from Muscle Shoals were destroyed by fire in transportation.

In reprocessing coated Muscle Shoal's AN at the Hercules Emporium, Pa., Plant a high pan explosion occurred at 276 - 278°F. The organic coating was thought responsible.

8. "Facts and Fancies about the Oppau Explosion (Ammonium Nitrate)." by J. Kendall - Chem. Met. Eng. 25, 949 (1921)

Speculates on the idea that propagation of a pressure wave, at high rate, due to transition between two crystal forms at 32°C was responsible for the explosion.

9. "Explosion of the Nitrate Plant at Oppau" by C. Commentz - Chem. Met. Eng. 25, 818 - 820 (1921)

Two terrific explosions disintegrated two large buildings containing the ammonium sulphonitrate leaving only a crater 50 ft. deep and 250 ft. in diam., and severely damaged Oppau (175,000,000 marks), sound and earth shock traveling 145 miles and causing damage at a distance of 53 miles (Frankfurt). 16000 blastings of the salt with dynamite had previously been made, to break up set nitrate, without mishap. Prior to explosion the color of the salt was reported to have changed from white to yellow and the storehouse temperature to have risen to 100 - 120°F. A violent gas engine explosion was also mentioned. The explosion was not followed by fire.

Attempts to detonate the salt later using heavy confinement and strong boosters produced only partial explosions. Heat and fire were ineffective.

Acidity was mentioned as a possible factor.

10. "Ammonium Nitrate" by H. Kast - Angew. Chem. 36, 72 - 75 (1923)

AN was detonated by 50 - 300 gm boosters of tetryl, and of picric acid, at 0.65 - 1.0 gm/cc in 2.5 - 10 cm columns in wrought iron tubes. The rates recorded range from about 1200 to 1900 m/s.

11. "Ammonium Nitrate as an Explosive" by R. M. Cook -  
Chem. Met. Eng. 31, 231 - 234 (1924)

Partial detonations were obtained in the following cases:  
5 gm AN initiated by 5 gm blasting gelatin in the ballistic mortar.  
160 gm AN initiated by a #8 cap, in a  $8\frac{1}{2}$  inch diameter concrete

block.

250 gm AN initiated by a #8 cap, in a  $1\frac{1}{2}$  x 8 inch capped pipe

nipple.

12. "Properties of Ammonium Nitrate. I. Freezing Point and Transition Temperatures" by R. G. Early and T. M. Lowry -  
J. Chem. Soc. 115, 1387 - 1404 (1919)

<u>Form</u>	<u>Stable - Temp. Range, °C.</u>	<u>Density - gm/cc</u>
1st	<-16	--
2d	-16 to 32	1.725
3d	32 - 84	1.66
4th	84 - 125	--
5th	125 - 170	--
Liquid	> 170	--

13. "Fire Risks with Ammonium Nitrate" by J. L. Sherrick -  
Army Ord. 4, 237 - 241 (1924)

3 gm AN in a test tube are not ignited by a black powder fuze.

At red-heat 5 gm AN merely decomposed, without flame, but leaving no residue.

100 gm AN dropped on iron, heated to cherry-red, decomposed without flame.

Aetna Powder Company claims explosions were obtained on dropping AN into heated iron vessels, at temperatures as low as 340°C.

Ferric Oxide Thermit, or its combination with a #8 cap had no effect on AN, but usually caused partial or complete burning of AN/wood pulp mixtures, contained in closed tin cans, at 0.71 gm/cc.

100 gm AN/wood pulp mixtures did not explode when initiated by #8 caps.

14. "Über Explosible Ammonsalze" by H. Kast -  
Zeit: Schiess u. Spreng. 22, 6 - 9, 30 - 34, 56 - 61, 77 - 80,  
99 - 102, 131 - 135 (1927)

Indicates a 3000 m/s detonation rate for AN if detonated high order.

AN will explode under a 16 - 20 cm fall of a 10 kg wt., or a 12 cm fall of a 20 kg wt.

Lead block expansion of AN given as 225 cc vs. 325 cc for picric acid.

Small amounts, up to about 30%, of ammonium sulphate have little or no effect on the explosibility of AN, but somewhat higher rates are recorded at the lower sulphate-contents.

These articles contain considerable data on impact, heat, lead block and detonation tests values for AN, AN - salt mixtures, AN - combustible mixtures, and for several other salts.

15. "Sur la force des matieres explosives d'apres la thermochemie" -  
by D. Bertholet - 3d ed., Paris, 1883

"Explosives" by Brunswick, 1912

"High Explosives" by Colver, 1938

"Explosives" by Marshall, 1932

"Schliess u Sprengstoffe" by Stettbacher, 1933

"Powder and Explosives" by Davis, 1943

Calculated constants: (Brunswick, Bertholet, Colver, Marshall above)

Heat of explosion, const. vol., water liq.	630 cal/gm.
Explosion Temperatures	2120°C.
Specific Volume	937 l/gm.

Marshall, above, states that the Oppau explosion was due to blasting with explosives and that several hundred of several thousand tons of AN explode.

Stettbacher, above, cites rates of 1200 - 1500 m/s for AN when incompletely decomposed, and 2000 - 2500 m/s under complete decomposition.

16. "Spontaneous Development of Heat in Mixed Fertilizers" -  
Ind. Eng. Chem. 38, 1298 - 1303 (1946) and

"Organic Material and Ammonium Nitrate in Fertilizer Mixtures" -  
Ind. Eng. Chem. 37, 59 - 63 (1945)

Spontaneous ignition of mixtures in large mass piles, of superphosphate - AN - organic matter can occur at 30°C air temperature due to the presence of free phosphoric acid in the superphosphate. Ignition is due to the release of nitric acid by the phosphoric acid.

17. "The Thermal Sensitiveness of Explosives" -  
A.C. 4439 - British Report.

Many different materials catalyze the decomposition of AN, and in the presence of from 1 - 20% of the following compounds AN may be exploded at about 200 - 300°C :

- Chromium trioxide
- Chromic hydroxide
- Chromic nitrate
- Chromic alum
- Potassium chromate
- Ammonium dichromate
- Potassium dichromate

18. "Study Ammonium Nitrate Explosive from Kelbar Powder Company -  
P.A. Tech. Rpt. 1008

A mixture of finely ground ammonium nitrate and 6.6% resin (0.05% moisture), had a Drop Test value ( 2 kg wt.) of 68 cm, was not appreciably affected in the Rifle Bullet, Pendulum Friction, and 120°C Vacuum Stability Tests. It was, however, initiated, in the Sand Test, when pressed lightly, by 0.4 gm mercury fulminate and crushed 36.4 gm Sand (TNT = 40, 80/20 Amatol = 28.5).

19. "Nitrate of Ammonia - Tests Made on Sensitiveness of AN at  
Experimental Laboratories of the Atlas Powder Company -  
Additional Tests" - 14 Nov. 1918  
P.A. Spec. Reports File No. 412 S.

Moist AN and zinc dust will explode.

Neutral AN chars sugar at 185°F, while acidic ( 3 drops of 93% nitric acid) AN ignites with sugar in 8 minutes at this temperature.

AN was unaffected when subjected at 100°C, to hammer blows on a steel anvil.

Partial detonations were obtained when 2 lb. samples of AN were initiated by #8 caps at 190°F. The AN was packed in closed cans 4 in. in diam., 5 in. tall. The AN was unaffected in about 75% of the trials.

AN subjected to the action of #8 blasting caps, a 10 gm tetryl booster, dynamite cartridges, and on electric arc (1000 - 1500°C) did not detonate.

4 lb. 9 oz. of AN heated in an agate-ware kettle ( in a steel cylinder) over a hot coke fire was subjected to the action of #8 caps which exploded at 155°C. One explosion was obtained in several trials.

20. "Explosibility of AN" - P.A. Spec. Reports File No. 1110.

Molten and solid AN were unaffected in the Pendulum Friction Test - steel shoe.

Molten AN was unaffected by blows from a 16 lb. sledge hammer, on steel rails.

AN was unaffected in the Rifle Bullet Impact Test using 0.30 cal. Service, AP, Tracer or Incendiary Ammunition. Slight smoke was noted in each trial where tracer or incendiary rounds were used.

A barrel of AN heated in a bon-fire, which burned around it, and subjected to the action of 6 Mk VII Boosters ( 3 in. TM Shell) exploded partially, about 3/4 of the AN being consumed. This is presumably the same test described in Spec. Report 1101.

21. "Tests to Determine the Possibility of Detonating AN" -  
P.A. Spec. Reports File No. 1101. 21 Jan. 1919.

No. 8 blasting caps did not explode AN at normal or elevated temperatures. Barrels of AN heated over a fire and subjected to the action of Mk VI Boosters (for 3 in. TM Shell) exploded partially.

22. OSRD Report 2014:

Properties of AN

Lead block expansion 165 cc. (Picric acid = 305)

Lead cylinder compression 54% of TNT

23. "Explosibility of Ammonium Nitrate and its Mixtures with Other Salts." - by Naoum and Aufschlager

Zeit. f. Schiess. u. Spreng. 19, 106 (1924); C.A. 18, 3721 (1924)

In the system of AN-potassium chloride, the explosibility decreases, at constant composition, with increasing fineness of the latter component. Heat of explosion and Trauzl Block data are given. A 75/25 - AN/potassium nitrate mixture was readily detonated in seamed iron tubes, initiator picric acid, at a rate of 1200 m/s; on the other hand a 1-1 mixture can only be detonated with difficulty. The latter mixture can be detonated, however, in a drawn iron tube; a rate of 1480 m/s was given.

24. "Report of Experiments to Determine whether Ammonium Sulphate-Nitrate as Prepared at Oppau Possesses Explosive Properties" - by G. Rotter. - Trans. Faraday Soc. 1924 (advanced proof); C.A. 18, 2251 (1924)

The only effects obtained under conditions of heavy confinement were due to development of a pressure merely sufficient to rupture the container. The experiments involved study of the sensitivity to shock heat and initiation.

25. "Limit Diameter of a Charge of Ammonium Nitrate" - by Belyaev and Khariton - C.R. acad. sci. U.R.S.S. 48, 256-8 (1945); C.A. 40, 4884<sup>8</sup> (1946)

Initiation, with 97/3 - AN/TNT, of dry AN at 0.7 - 0.8 gm/cc, in cardboard, or glass, tubes led to stable detonation at diameters above 8-10 cm. Damping, below this diameter was more abrupt at the smaller charge diameters. Under water or in concrete the minimum diameter was 3-4 cm.

26. "Explosibility of Ammonium Nitrate and its Mixtures with Other Salts" - by Naoum and Aufschlager - Zeit. f. Schiess. u. Spreng. 19, 35 (1924)

Mixtures containing up to 50% of AN; with ammonium sulphate can be exploded by sufficiently strong initiators, but a 40% AN mixture is not practicable to explode. Equal parts of AN and ammonium sulphate, mixed dry in 8 mm seamless steel tubing of 60 mm I.D., initiated by 185 gm Astralit, detonated at 1070 m/s. The same mixture prepared in the wet way (double salt) could not be exploded, thus showing the effect of fineness of the sulphate. When 200 gm of picric acid was used as initiator the rates obtained for the mechanical mixture and double salt were 1400 and 1030 m/s respectively.



27. "The Explosive Properties of Mixtures Containing Ammonium Nitrate." - by A. J. der Weduwen  
Chem. Week - blad. 19, 1922, 341-2; C. A. 16, 3760 (1922)

Claims AN or its mixtures with up to 50% of an inert salt can be made to explode violently if initiated by 50 gm TNT. 250 gm of salt mixture was used, and its effect on an iron plate observed.

28. "The Decomposition of Ammonium Nitrate During Evaporation." - by V. A. Klevke - J. Chem. Ind. (Moscow) 1935, No. 1, 53-4; C.A. 29, 3469 (1935)

Almost no decomposition of AN occurs during evaporation of its solutions at atmospheric or reduced pressures.

29. "The Spontaneous Decomposition of Ammonium Nitrate Melts." - by Heinrich Tramm and Hermann Velde - Angew. Che. 47, 782-3 (1934); C.A. 29, 699<sup>9</sup>(1935)

Chlorine free AN which had become acidic, by slow ammonia evolution, on long standing at 175°C, in the molten condition, did not decompose seriously. A chlorine containing, but alkaline or neutral, melt at 175°C did not decompose more rapidly than chlorine free material. Relatively small amounts of free acid and chlorine combined may, however, cause spontaneous decomposition at temperatures as low as 140°C.

30. "Chemical and Physical Properties of Oppau Ammonium Sulphate - Nitrate." - by Robert Robinson, H. H. Thomas, A. F. Hallimond and William Bragg.  
Trans. Faraday Soc. 1924 (advance proof); C. A. 18, 2250 (1924)

The investigation uncovered no factors which might have caused the disaster.

31. "The Explosiveness of Fertilizers Containing Ammonium Nitrate" - by N. S. Torsuev - J. Chem. Ind. (Moscow) 13, 102-104 (1936); C. A. 30, 3150<sup>7</sup>(1936)

AN coated with paraffin explodes more strongly than pure AN. The addition of ammonium sulphate to AN reduces its explosibility, but organic matter has the opposite effect.

32. "Detonation of Ammonium Nitrate", - by Laffitte and Parisot  
C.r. 203, 1516 - 1518(1936); C. A. 31, 1615<sup>7</sup>(1937)

AN when mixed with 1.5-2% magnesium, aluminum, dinitro or trinitro naphthalenes can be completely detonated by mercury fulminate, in 7-21 mm columns, if an amount not exceeding 30 gm is used. This is not true of pure ammonium nitrate.

33. "Nixon Explosion Emphasizes Effect of Organic Impurities" - by R. D. Bashford - Chem. & Med. 30, 622 (1924)

States AN is not an explosive in the absence of organic impurities.

34. "Ammonium Nitrate by Itself is Not an Explosive" - by G. N. Norman - Chem. & Med. 30, 622 (1924).

Other compounds are stated to be the cause of explosions experienced.

35. "Safety in the Manufacture of Nitric, Sulphuric, and Mixed Acids and Nitrate of Ammonia as Used in the Manufacture of Explosives." - by S. H. Kerahaw Ind. Eng. Chem 18, 4(1926); C. A. 20, 504 (1926)

Safety practices are discussed.

36. "The Decomposition and Stability of Ammonium Nitrate in the Presence of Oxidizable Material." - by A. Findlay & C. Rosebourne - J. Sec. Chem. Ind. 41, 58T (1922); C. A. 16, 1319 (1922)

AN can be heated 100 days at 100°C without appreciable decomposition, but in the presence of woodmeal decomposition soon occurs with evolution of carbon dioxide and nitrogen. The cellulose, not the resinous matter present, is responsible for the decomposition, and starch was found to have a similar action. The interaction was prevented by urea but not by diphenylamine or phenylbenzyl ether.

37. "Recovery of Ammonium Nitrate from Amatol. Explosion of Ammonium Nitrate Plant of Ammonite Company". - by R. N. Schreve - Ind. Eng. Chem 23, 506(1931); C.A. 25, 3171(1931)

The contents of a grainer detonated and exploded recently produced AN temporarily stored near by. No explanation given. 14 references are listed.

38. "The Decomposition of Ammonium Nitrate by Heat" - by H. L. Saunders J. Chem. Soc. 121, 698-711(1922); C. A. 16, 2225(1922)

Pure ammonium nitrate decomposes to the extent of 98% , yielding nitrous oxide and water. The course of the decomposition is unaltered over the range 210-260°C. At same point near 300°C other oxides of nitrogen are evolved and the reaction proceeds explosively.\* At the moment of explosion the nitrate decomposes yielding NO<sub>2</sub>, NO and N<sub>2</sub> in the molar ration 2:4:5. Chlorides when present, even to the extent of 0.1%, catalyze the decomposition presumably due to the formation of chlorine. Sulphates are without characteristic action and sodium nitrate, when present in small amount, has no effect at temperatures below 250°C.

\*Gas phase explosion only.

39. "The Explosion of Oppau," Anon  
J. Soc. Chem. Ind. 40, 381-R (1921); C.A. 16, 164(1922).

Discusses the possible causes of the explosion.

Formation of  $\text{NCl}_3$ , via Chlorine acting on AN. The chlorine was assumed formed from a chloride and AN.

Formation of unstable double salts between AN and ammonium sulphate.

The presence of acidity which could, by interacting with ammonium sulphate, cause autocatalytic exothermic reactions.

40. "The Explosion of Two Cans of Ammonium Nitrate at the Aktiengesellschaft-Lignose Explosive Factory at Kriewald O.-S. on 26 July 1921" - by D. W. Bramkamp.  
3 eit. Schiess. u. Spreng. 17, 67(1922); C. A. 16, 2605 (1922)

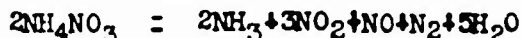
Two cans exploded when their contents were blasted to break up the set masses.

The author refers to Escales "AN Explosives", p. 40, who related that 200 gm of AN was not detonated by 1-5 gm mercury fulminate, but was strongly exploded by 20-30 gm of Bellit (AN + DNB). Pressed AN was exploded by TNT detonating cord.

Tests of AN from Kriewald were made. Pressed in cases it was not detonated by two No. 8 caps, but about half the mass exploded when a cartridge of Wetterlignosit was used. 100 gm AN tamped into an iron beaker was not detonated by a No. 8 blasting cap. 200 gm AN tamped in an iron beaker was exploded completely when subjected to the action of a cartridge containing a mixture of 47 gm AN with 2 gm TNT, initiated by a No. 8 cap.

41. "The Explosiveness of Molten Ammonium Nitrate" - by Rudolph Kaiser  
Angew. Chem. 48, 49-50 (1935); C. A. 29, 3161<sup>4</sup>(1935)

AN heated above about 200°C decomposes according to the following reaction, which is rapid at and above 260°C.



A small amount of AN heated in an evacuated bulb yielded a gas phase, containing a mist, which exploded after a fairly long period at 260-269°C.

42. "Fire and Explosion Hazards of Ammonium Nitrate"  
Fertilizer Bases, Bull. of Res. No. 20  
Underwriter's Laboratories, Inc.

Ammonium nitrate - sulphate mixtures containing no more than 40% AN, or AN - calcium carbonate mixtures containing no more than 61% AN do not constitute a fire or explosion hazard.

43. "The Decomposition of Ammonium Nitrate by Heat." by Shah and Oza  
J. Chem. Soc. 1932, 725-736.

Confirms the statements of reference 38 with respect to the fact that gas phase explosions occur at some point near 300°C, when A.N. is heated.

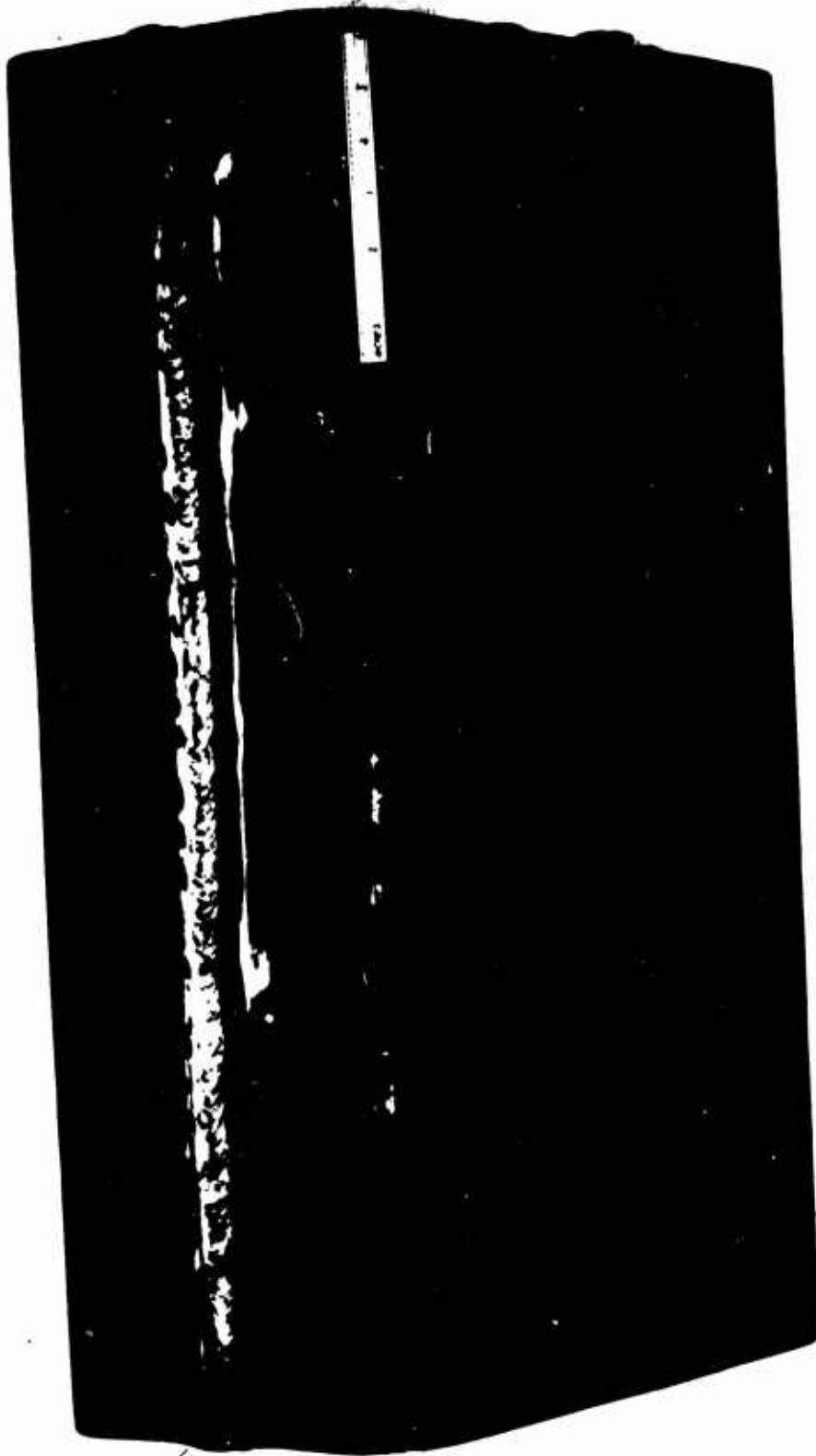
Summary:

a. AN at a density of 0.7-1.0 gm/cc, can be caused to detonate by the action of sufficiently strong boosters (e.g. 50-100 gm tetryl) in columns 8-10 cm in diameter when confinement is weak (paper), and in columns 3-4 cm in diameter when confinement is strong (steel). Rates in the range 1000-2500 m/s, depending upon conditions imposed, have been reported. Rate and sensitivity depend on AN particle size, density, confinement and charge diameter.

b. Due to the action of heat alone gas phase explosions have been noted at 260°C and above.

c. Certain inorganic contaminants, in small amount can cause AN to decompose explosively in the range 200-300°C, while certain active organic contaminants, e.g. resins, starch, sugar, react with neutral AN with concomitant charring and gassing. Moist zinc dust and AN will explode, while in the presence of phosphoric acid, at 30°C, mixtures of AN and organic combustibles may ignite spontaneously, or explode at elevated temperatures.

d. At some point above 120°F (probably the 125°F transition temperature) AN is far easier to explode than below this temperature. Molten AN can be exploded by boosting in spite of its relatively high density 1.4 gm/cc.



M-33017

April 1947

PICATINNY ARSENAL

ORDNANCE DEPARTMENT

Nitrate Fertilizer Sensitivity Test  
Container (Simulated Navy All-Steel Powder Container  
Manufactured from  $\frac{1}{2}$  Inch Thick Steel ) Prior to Test.  
P.A.T.S. Data Book No. 2246

(L)



M-33018

April 1947

PICATINNY ARSENAL

ORDNANCE DEPARTMENT

Nitrate Fertilizer Sensitivity Test  
Container (Simulated Navy All-Steel Powder Container  
Manufactured from  $\frac{1}{4}$  Inch Thick Steel) Prior to Test.  
P.A.T.S. Data Book No. 2246

(L)



M-33028

April 1947

PICATINNY ARSENAL

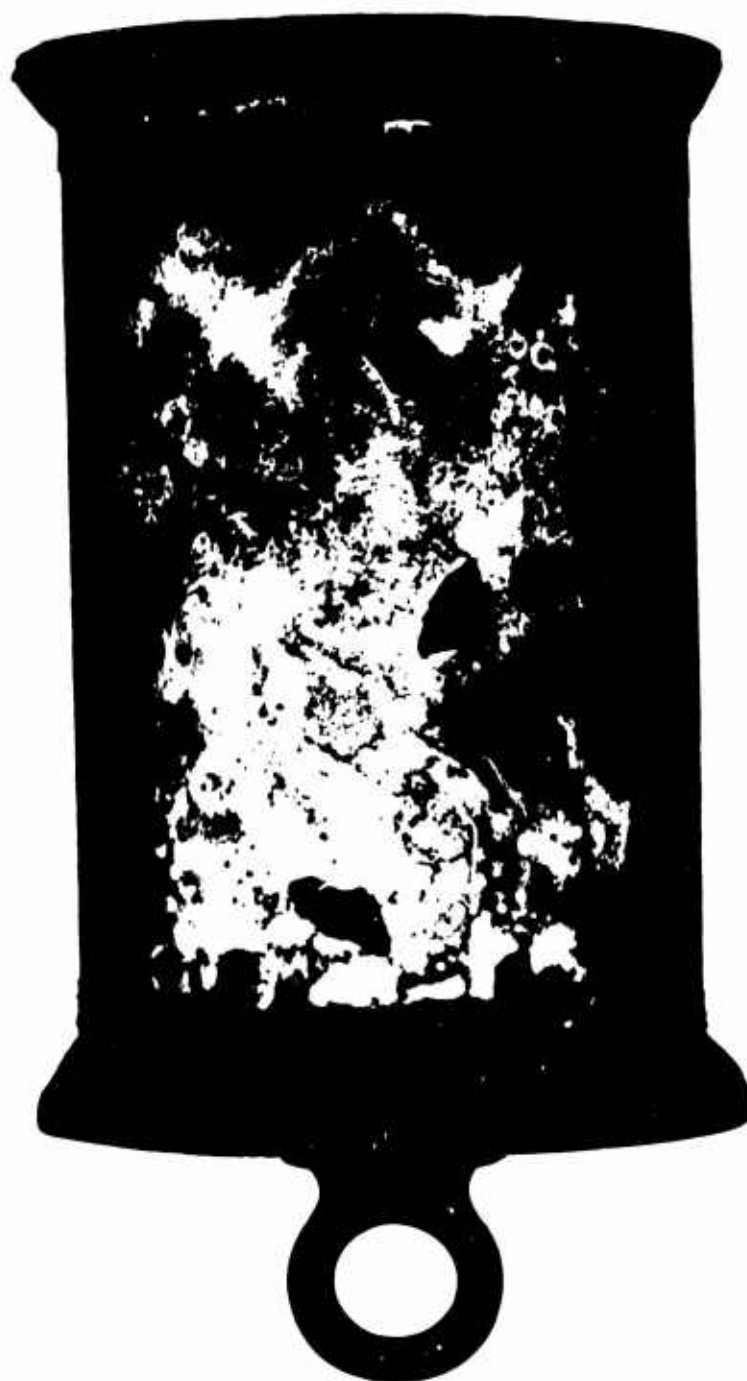
ORDNANCE DEPARTMENT

Nitrate Fertilizer Sensitivity Test  
Container, Showing Damage

(Loaded with Approx. 50 Lbs. Nitrate Fertilizer and Bagging)  
P.A.T.S. Data Book No. 2246  
Test No. 2

(L)





1

M-33030

July 1947

PICATINNY ARSENAL

ORDNANCE DEPARTMENT

6" x 11" Test Bomb, 5/16" Wall, Used for Heating Tests

(T)

ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED

(U)



Dented 1/8" Steel Plate and Supports After Test



### Deformed Supporting Bomb A After Test

DA 33030/1 July 1947 PICATINNY ARSENAL ORDNANCE DEPARTMENT  
Cratering Effect of Charge of Fertilizer Nitrate and  
Bagging with CO & N<sub>2</sub>O Gases (1

החלטתו של בית דין זה, תהיה כפוף להחלטת בית דין זה.

(11)



M-33260 April 1947 PICATINNY ARSENAL ORDNANCE DEPARTMENT

Nitrate Fertilizer Sensitivity Test  
Container, Showing Damage

(Loaded with Approx. 100 Lbs. Nitrate Fertilizer and Bagging)  
Test No. 1

P.A.T.S. Data Book No. 2246 (T)



M-33502

June 1947

PICATINNY ARSENAL

ORDNANCE DEPARTMENT

Bomb and Cap

After Explosion of 27 June 1947 .. Top View

(T)



M-33503

June 1947

PICATINNY ARSENAL

ORDNANCE DEPARTMENT

Bomb and Cap

After Explosion of 27 June 1947 - Side View

(T)



M-33503/1 July 1947

PICATINNY ARSENAL

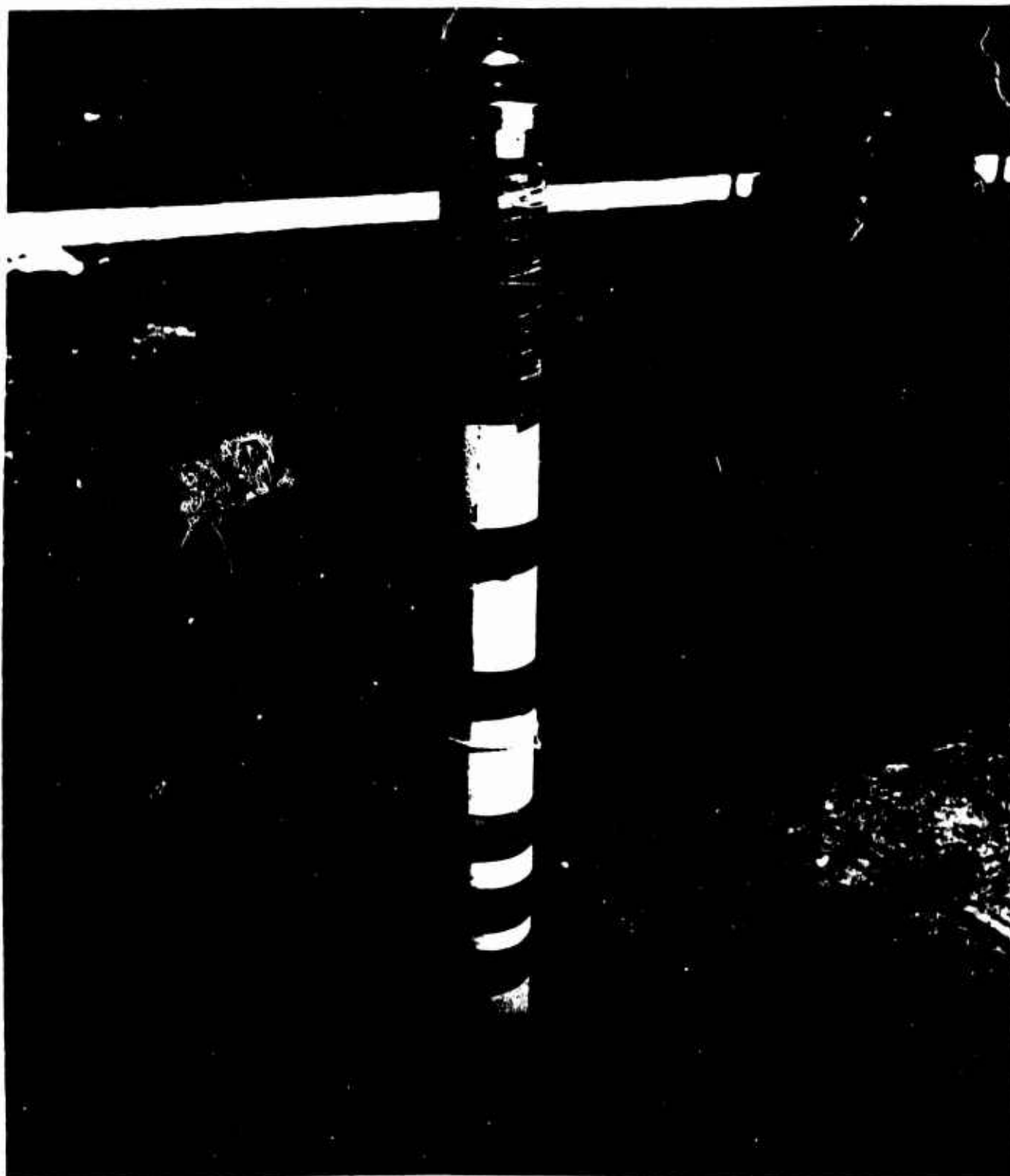
ORDNANCE DEPARTMENT

Bomb After Explosion of 2 July 1947

(T)



M-33503/2      July 1947      PICATINNY ARSENAL      ORDNANCE DEPARTMENT  
Bomb After Explosion of 3 July 1947      (T)



M-33503/3 July 1947 PICATINNY ARSENAL ORDNANCE DEPARTMENT

2.5" x 36" Test Bomb, 1/8" Wall, Equipped for Electrical Heating (T)